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EFFECT OF TEMPERATURE ON THE PLASTICITY OF TITANIUM

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16. Abstract

Titanium was studied to show the effect of temperature on its plasticity. The reduction of the complete elongation at medium temperatures is not the result of brittleness, but the reduction of its plastic deformation corresponding to the decrease of deformation hardness during an increased temperature. Elongation of low-alloyed titanium alloys during reduced temperatures, even to negative temperatures, increases the same as for pure titanium. In this way, titanium and its alloys are suitable for cryogenic equipment.

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EFFECT OF TEMPERATURE ON THE PLASTICITY OF TITANIUM

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Recently much attention has been paid to the study of the temperature dependence of the plasticity of titanium and its alloys [1-5]. However, features of the temperature dependence of the relative elongation cannot be explained simply. The relative elongation is a widely used characteristic for estimating the qualities of material. Therefore, it is interesting to study the effect of temperature on the relative elongation and determine the reasons causing the peculiarities of its temperature dependence. /89*

To carry out the experiments a very pure (iodide) titanium, a technically pure titanium (the TG100 sponge) and alloys were used, produced by using the TG100 sponge. The specimens tested had a diameter of test section of 5 mm, and a 5-multiple length of test section. In some cases, specimens were tested with a diameter of 6 mm and a 5- and 10-multiple length of test section. Specimens were tested at a speed of approximately 1.5 mm/min in an air medium at high temperatures and in a quenching agent medium (liquid nitrogen or a mixture of nitrogen and benzene) at low temperatures.

Fig. 1, a shows that in iodide and technical titanium the relative elongation determined on specimens with a diameter of 5 mm and 25 mm in length at -196° has very high values (67 and 59%, respectively). As the temperature is increased, the relative elongation is reduced;at 200-300° it changes relatively little and then again decreases, reaching a minimum (approximately 20%) at 500°. With a further increase in pressure, the relative elongation increases sharply and falls steeply when entering the β-region. Figure 1 also shows the relative elongation of titanium

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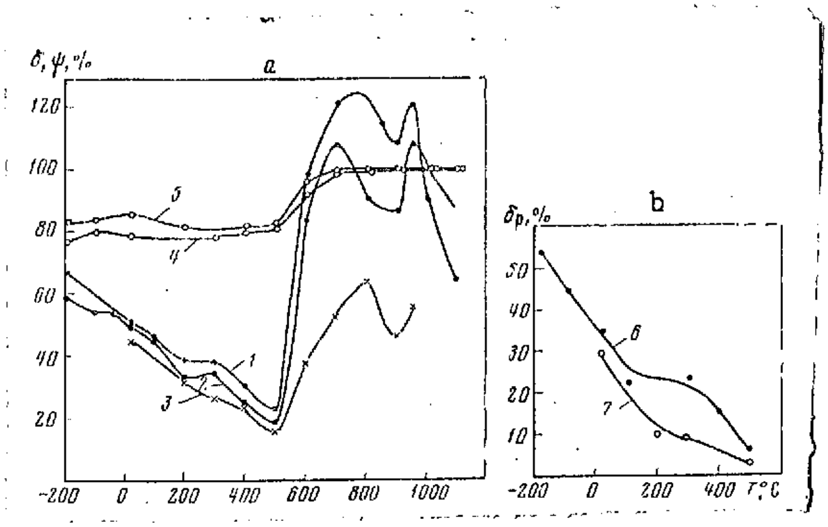

Fig. 1. The relative elongation (1, 2, 3) and relative reduction (4, 5) of unalloyed titanium (a) and the uniform part of the relative elongation of titanium iodide (b) depending on the test temperature.

1, 5 - titanium iodide, 5 x 25 mm diam. specimens; 2, 4 - technically pure titanium, 5 x 25 mm diam. specimens; 3 - titanium iodide, 6 x x 60 mm diam. specimens; 6 - 5 x x 25 mm diam. specimens; 7 - 6 x 60 mm diam. specimens.

iodide specimens with a 10-multiple bearing length (6 x 60 mm diam.) depending on temperature. In this case, the general level of elongation is lower than in shorter, 5-multiple specimens, especially at temperatures above 500°. Furthermore, when testing long specimens, there was a noticeable reduction in the decrease of elongation at 200-300°. As a whole, the information shows that for very pure titanium there is a reduction of the relative elongation at an increased temperature from -196° to +500° and during the transition to the β-region.

The course of the temperature dependence of the relative elongation does not coincide with that of other plasticity characteristics during temperature change. Hence, the relative reduction during increased temperatures rises, especially at temperatures above 500° (Fig. 1, a). At 700-800°, the relative contraction reaches values close to 100%, and during further temperature increases, specimens are elongated into a needle, without showing any signs of embrittlement. When titanium is /90
deformed having predominantly compressive forms in its stressed state (swaging, rolling, forging) it can fracture at room

temperature. In particular, titanium iodide when forging from a circle to a square is fractured by a shear along the forging cross at a deformation stage of approximately 40% (according to the relative increase of the cross-section area). During swaging of cylindrical specimens (10 x 15 mm diam.) of industrial titanium on a power press, fracture occurs during reduction by 60%. When rolling industrial titanium, cracks on the edges are seen during a total degree of reduction of approximately 85-90%. However, when the temperature is raised to 100° and above, fracture with the deformations shown does not occur during the practically attainable degrees of deformation.

Consequently, a reduction of the relative elongation during average temperatures in the β-region does not reflect the actual change of plasticity of titanium with the increase of the test temperature.

When examining the outward appearance of titanium iodide specimens tested for elongation, it was found that at -196°, intensive deformation occurred along the whole length of the specimens with clearly defined cylindrical sections (uniform deformation) and with a neck (concentrated deformation). With a temperature increase, the tapering of the specimen on its cylindrical section is reduced, and at 500°, there are no traces of deformation on the section between the neck and the heads of specimens. The results of measuring the deformation on half of the distance between the neck and the heads are shown in Fig. 1, b in the form of uniform elongation, obtained by conversion from the relative reduction depending on temperature. As this figure shows, the uniform elongation of titanium iodide on specimens with a 5-multiple bearing length is very large at -196°, decreases with an increase of temperature to 100°, at 200-300° the change is little, and again is reduced at 500°. The uniform elongation on longer, 10-multiple specimens with temperature increases from 20 to 500° is reduced, asymptotically approaching the axis of X, without a plateau at 200-300°. Detailed measurement of deformation on the length of specimens examined showed that with an increase of test temperature, apart from a decrease of uniform /91 deformation, there is an increase in the length of the neck, especially at an interval of 20 to 300°.

The "flattening" of the neck to a great length causes the increase of the total elongation, since a decrease of the uniform elongation is compensated by an increase of elongation in the neck, especially in relatively short specimens, the necks of which are "flattened" for almost the whole length of the test section. At the same time, there is an increase in the "uniform" elongation when this is determined by the normal method, since here the diameter is measured near the neck. The "flattening" effect of the neck is less noticeable when determining the elongation on longer specimens; apart from this, there is a cylindrical section of the specimen on which the "uniform" deformation section is measured correctly. Therefore, there is no horizontal plateau at 200-300° on the curve for the complete and uniform elongation of long samples, depending on temperature. During further increase of temperature (above 500°), deformation hardening is not only insufficient to create a uniform deformation, but for the localization of a deformation in the neck. A phenomenon occurs, called by S.I. Gubkin "ductility," when the specimen is stretched until a cone forms. Here, as in amorphous bodies, the longer the specimen "has time" to expand before fracture, the greater its resistance to deformation. In titanium, the resistance to deformation with an increase of temperature from 500° is quickly reduced and there is a corresponding increase in the relative elongation. Deformation in this region of temperatures is not uniform (Fig. 1, a) and the higher the temperature, the greater it is. The transition to the β-region is accompanied by a reduction in volume of the test section of the specimen which has been deformed. The length of the cones into which the specimens have been elongated is shortened, and the relative elongation is considerably reduced. Obviously, this is linked with a difference in the properties of crystal lattices of α- and β-modifications of titanium.

The reduction of deformation hardening during increased temperature is peculiar to all metals investigated at the present time [6], with the exception of those cases when there are such specific phenomena as the precipitation of disperse phases during deformation, etc. Therefore, it must be expected that features of temperature dependence of the relative elongation are peculiar not only to titanium, but other metals. This assumption was tested on aluminum, lead, nickel and armco iron. Figure 2 shows the results of testing specimens with a diameter of 5 mm and a length of 25 mm. The temperature dependence of elongation and

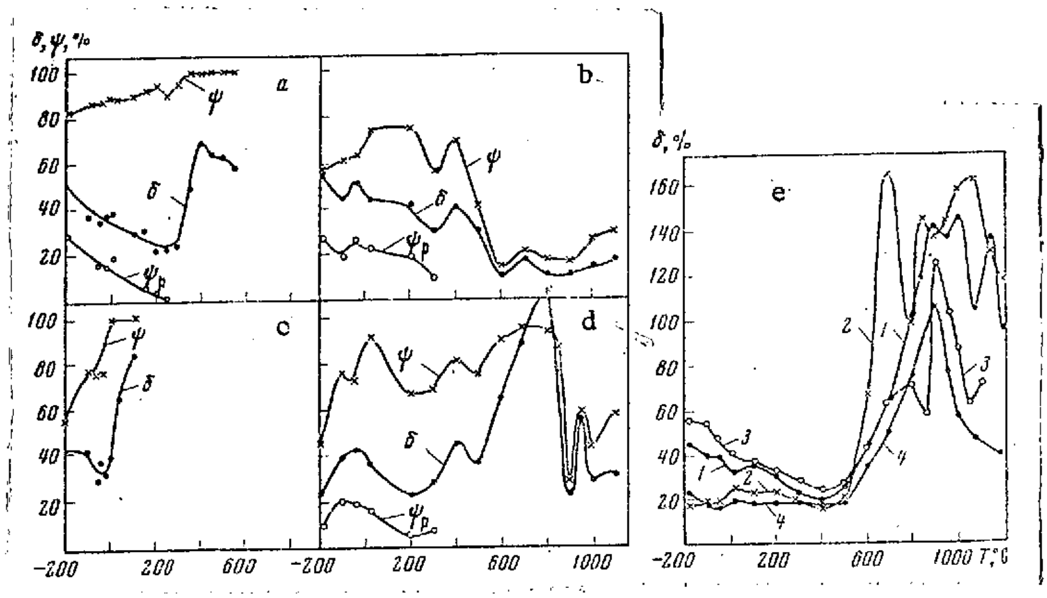

Fig. 2. The relative elongation, relative reduction and uniform reduction of metals depending on temperature.
a - aluminum; b - lead; c - nickel; d - armco iron;
e - titanium alloys with: 1.82% V (1); 8.07% V (2);
6% Zr (3); and 4% Al (4).

reduction of nickel (Fig. 2, c) and armco iron (Fig. 2, d) looks rather different. In nickel, when there is a temperature increase from -196°, as in other metals shown above, the complete elongation and uniform reduction is reduced, but the complete relative reduction increases. However, at temperatures above 400°, owing to intergranular fracture, embrittlement takes place, and both characteristics -- reduction and elongation -- are sharply reduced. In armco iron, the overall picture is one of distorting cold shortness during negative temperatures and red shortness at high temperatures.

In this way, on the basis of information shown, it can be concluded that the reduction of the relative elongation is peculiar to pure metals at a temperature increase to 0.4-0.5 T_{melt}°K, as the result of the decreased uniform amount of deformation. This reduction does not indicate embrittlement, but reflects the change in stability of the plastic moldability of a stretchable bar, due to the reduction of deformation hardening with increased temperature. The concentrated part of deformation, which, as known [7], does not depend on the stability of plastic deformation, but is determined by the development of defects present in the material or occurring during deformation, contributes mainly /92 to relative reduction. Therefore, the relative reduction continuously increases as the temperature rises. The general form indicated for the temperature dependence of relative elongation and reduction is distorted when there are such types of embrittlement as cold shortness, hot shortness, red shortness, etc. A characteristic of these is the simultaneous reduction of elongation and contraction.

In titanium alloys, the general view of the temperature dependence of elongation and reduction is the same as for unalloyed titanium. However, there are differences, mainly in the left, low-temperature part of the diagrams. Figure 2, e shows as an example temperature dependences of relative elongation of titanium alloys with zirconium, vanadium and aluminum. The figure shows that in low-alloyed alloys, containing zirconium or vanadium in dissolution limits in α-titanium, the relative elongation is high at -196°, and decreases as the temperature increases to 500°. In higher alloyed alloys, especially two-phase titanium alloys with vanadium and alloys with aluminum, elongation at -196° is low in comparison with that of titanium or low-alloyed alloys. In this case, when the temperature rises, the relative elongation increases. At high temperatures, the outward appearance of the temperature dependence of relative elongation in alloys and unalloyed titanium is identical: as the temperature rises from 500°, elongation increases and decreases during the transition to the β-region.

The reason for the change of the elongation dependence on temperature in the low-temperature region, apparently, is that during alloying, simultaneously with the increase of strength, there is a decrease in the uniform part of deformation (if solid solutions are formed, and do not decompose during deformation). A decrease in the uniform part of deformation is more noticeable at low temperatures at which uniform elongation forms the main part of complete elongation. At medium temperatures, concentrated elongation contributes most to complete elongation, and this depends less on alloying than uniform elongation. Therefore, the complete elongation in alloys and pure titanium has its closest values in medium temperatures. In this way, one can /93 understand the reason for the different form of the temperature dependence of elongation in early and later research. In early research, the titanium used was contaminated with impurities, which caused a significant hardening and reduction of uniform deformation. Recently, very pure titanium has been used with low strength and high uniform deformation.

Conclusions

1. The reduction of the complete relative elongation of titanium at medium temperatures and in the β-region is not the result of brittleness, but reflects the reduced stability of plastic deformation according to the reduction of deformation hardness during increased temperature; this is not only true of titanium, but other metals, which have a uniform deformation and neck at low temperatures, and do not tend toward specific types of brittleness.

2. In low-alloyed titanium alloys, when there is a reduction of temperature to negative values, elongation increases as for pure titanium. This makes titanium, and alloys similar to it, suitable for cryogenic equipment; attention must be paid to relative reduction when studying the temperature variation of plasticity of metals and alloys, including titanium and its alloys (for example, to estimate their deformability). The simultaneous reduction of both characteristics (elongation and reduction) shows the occurrence of brittleness; the reduction of elongation alone, while reduction increases, must not be looked upon as reduction of plasticity; quite the reverse, plasticity increases proportionally to the increase of relative reduction.

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